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United States
Environmental Protection
Agency

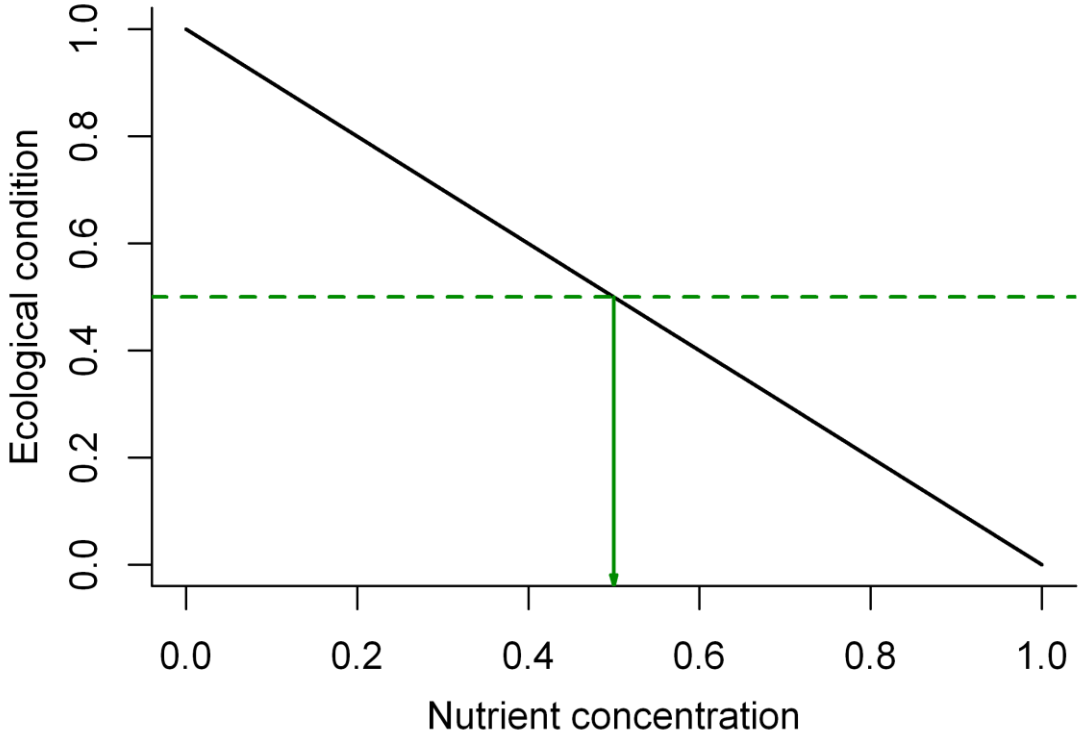
Using Stressor-Response Relationships to Derive Numeric Nutrient Criteria

Goal: Discuss the technical approaches that will improve the accuracy and precision of the estimated relationship between stressor and response variables used to derive numeric nutrient criteria

Outline

- Background
- Common questions

What is a Stressor-Response Approach?



Background

- Relationship between total phosphorus and chlorophyll-a used to guide management of lakes (Dillon and Rigler, 1974).
- Stressor-response relationships described as an approach for deriving nutrient criteria for different waterbodies (EPA 2000).
- Guidance on the use of stressor-response for nutrient criteria derivation reviewed by EPA SAB (2010).
- Final guidance document on use of stressor-response released (2010).

Common Questions about the Stressor-Response Approach

- Does a strong stressor-response relationship prove that a cause-effect relationship exists?
- How much data do I need?
- What are the thresholds for the response?
- Why are my relationships noisy?

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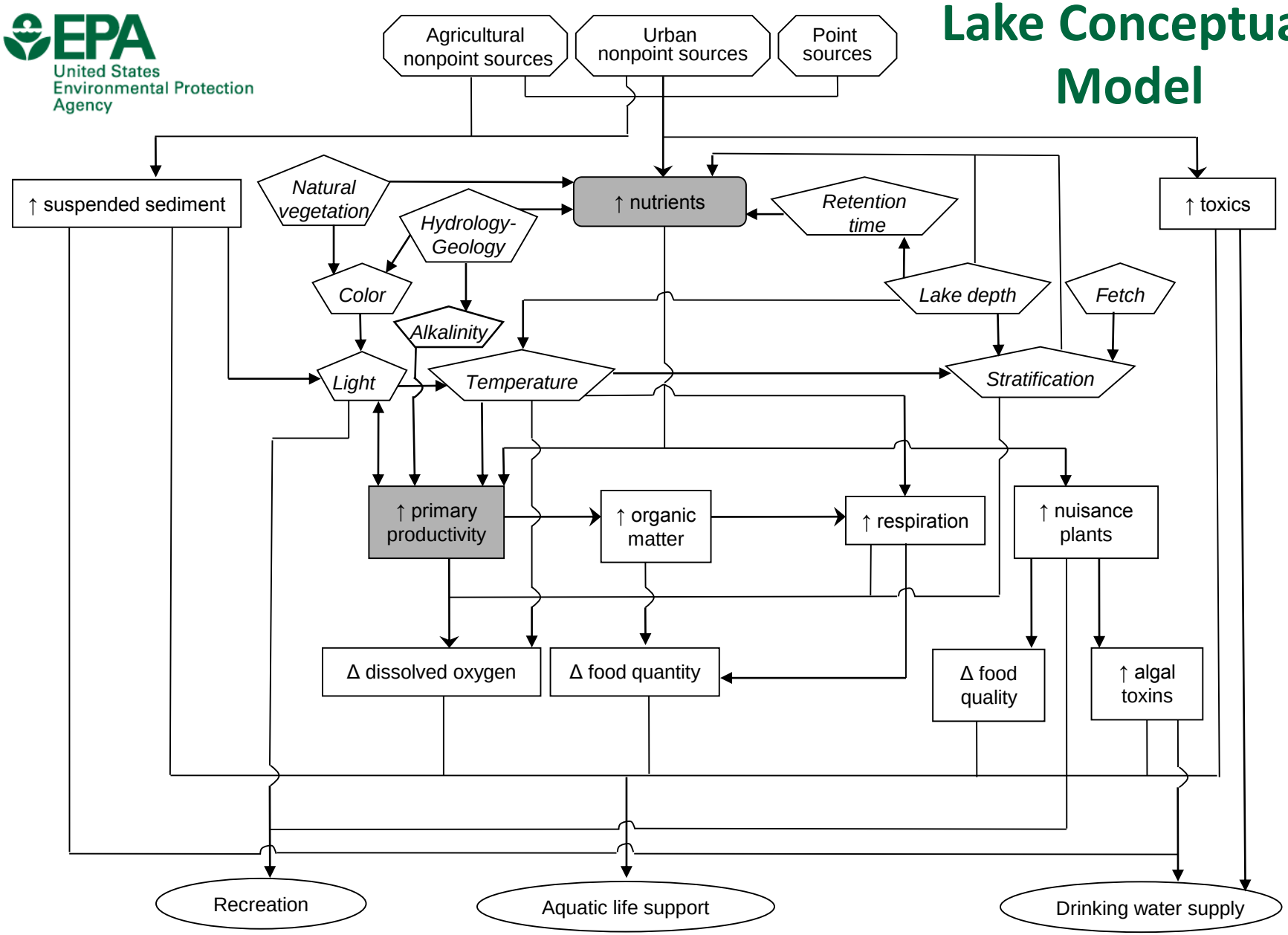
Cause-Effect Relationships

Stressor-response relationships do not prove causality, but they don't need to.

- Causal relationships between increased nutrients and ecological effects have been established by observational and manipulative studies conducted in the field and the lab.
- Conceptual models represent the known relationships between human activities, changes in nutrient concentrations (nitrogen and phosphorus), biological responses, and support for designated uses.

Lake Conceptual Model



Stressor-Response Relationships and the Conceptual Model

- A stressor-response relationship provides an empirical representation of a relationship shown in the conceptual model.
- The accuracy and precision of this representation depends on the details of the statistical analysis and the available data.

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Data Requirements

- Data need to be nominally matched in time and space.
  - For example, nutrient measurements should be collected in the same stream reach as biological response data.
  - Matched data become harder to find as the number of other variables used in the model increases.
- Estimating a simple linear regression requires a minimum of 10 independent samples per degree of freedom (e.g., 10 samples per estimated coefficient).
  - Example: chlorophyll-a = $b_0 + b_1 \times TP$.
  - Two coefficients (b_0 and b_1) requires a minimum of 20 samples.
  - More data is always better.

Data Requirements (cont.)

- More data are required as covariates are considered.
  - Example: chlorophyll-a = $b_0 + b_1 \times TP + b_2 \times Canopy + b_3 \times Substrate$.
  - Four coefficients requires a minimum of 40 samples.
- Modelling relationships as curves requires more data.

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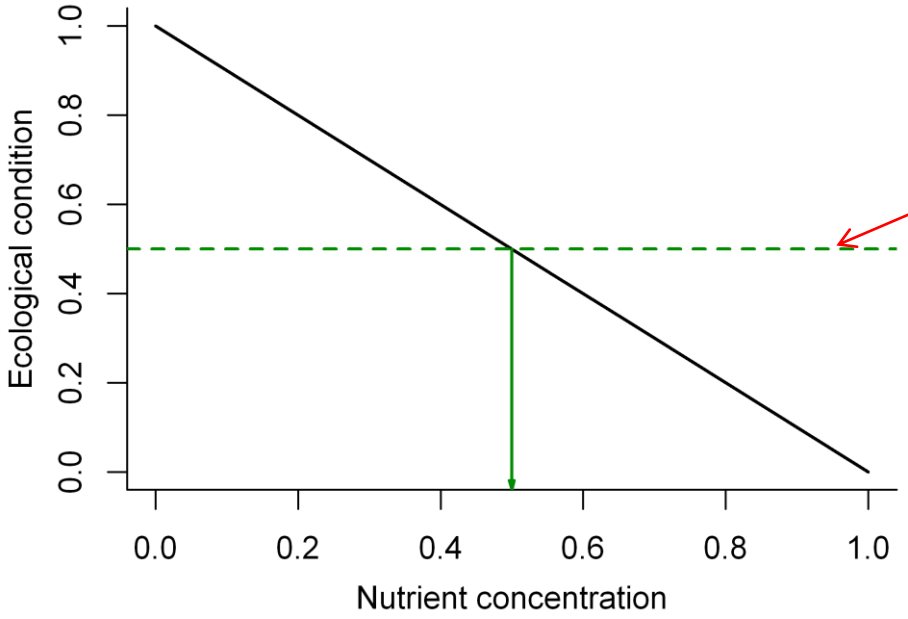
Thresholds for the Response

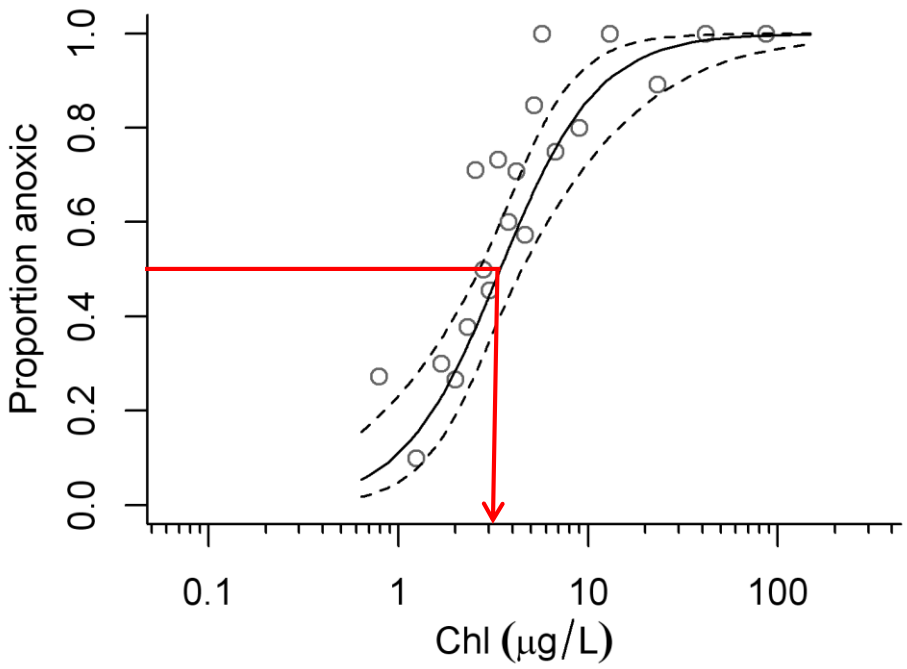


Where does this value come from?

Thresholds for the Response

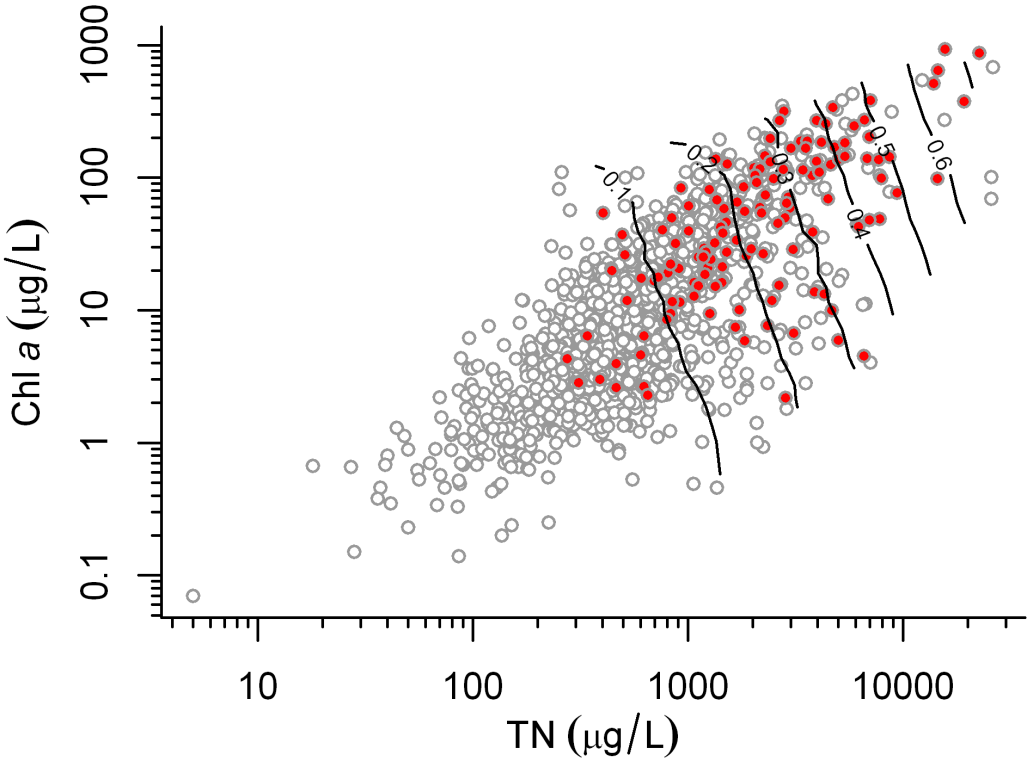
- Thresholds should link directly to an assessment endpoint.
  - Lake examples:
    - Excessive nutrients → higher microcystin → impaired drinking water
    - Excessive nutrients → lower dissolved oxygen → impaired aquatic life
  - Estuary example:
    - Excessive nutrients → increased turbidity → loss of SAV
- Thresholds for aquatic life uses can also be derived from reference conditions approaches.

Relationship Between Chlorophyll-a and Hypolimnetic Hypoxia



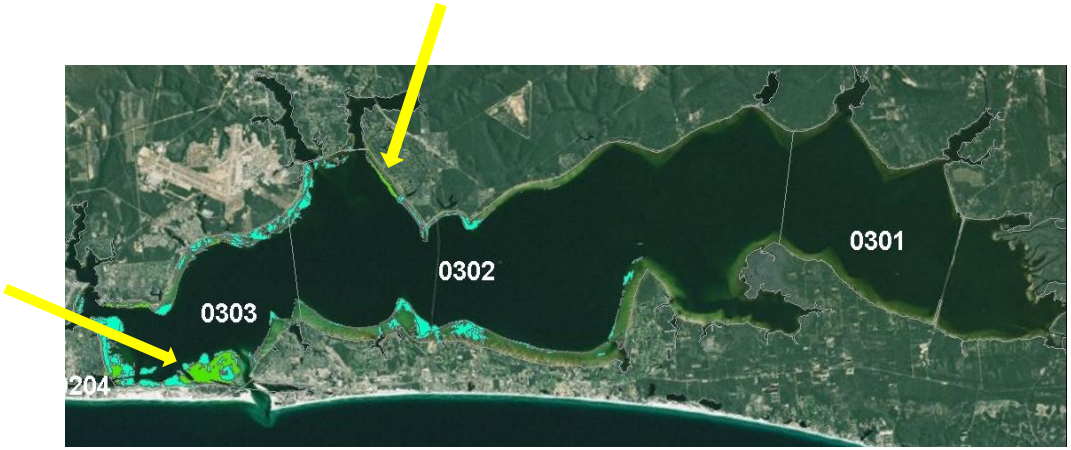
In lakes that stratify seasonally, chlorophyll-a in the epilimnion is strongly associated with hypoxia in the hypolimnion.

Relationship Between Lake Chlorophyll-a Concentration and Microcystin Occurrence



Red circles = lakes with microcystin ≥ 1 µg/L (World Health Organization risk level).
Contours = probability of exceeding microcystin ≥ 1 ug/L.

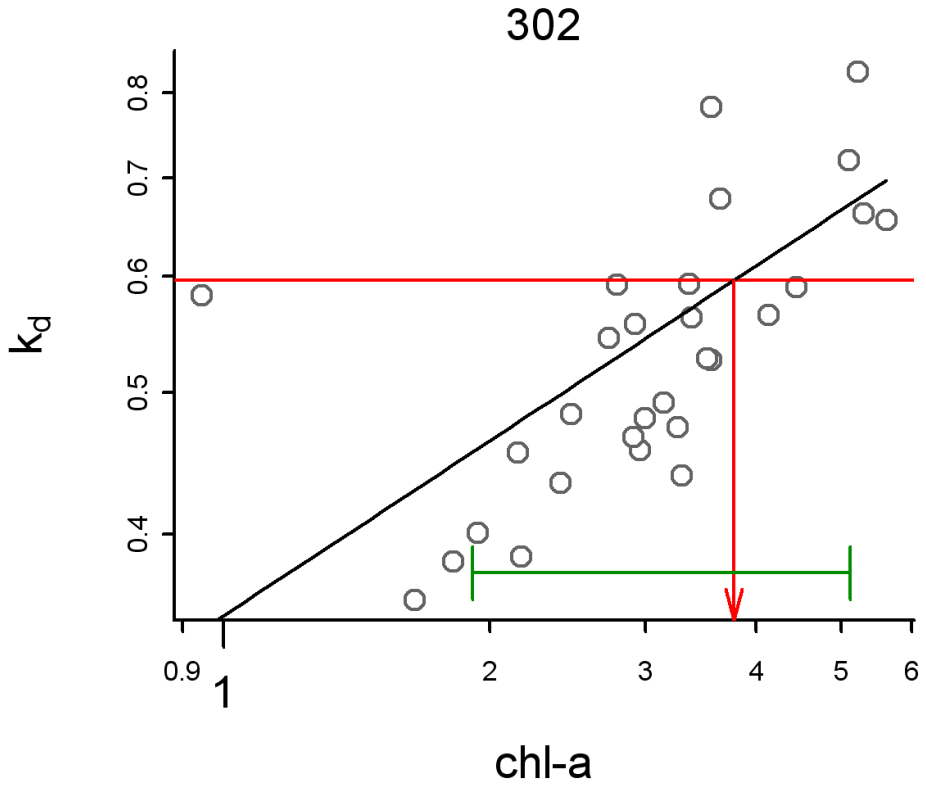
Threshold Based on Extent of SAV



Estuary Segment	SAV Depth Target (m)	K_d Target (1/m)
0301	None	-
0302	2.7	0.6
0303	3.3	0.5

Threshold Based on Extent of SAV

Water clarity provides a threshold from which we estimate a chlorophyll-a criterion.



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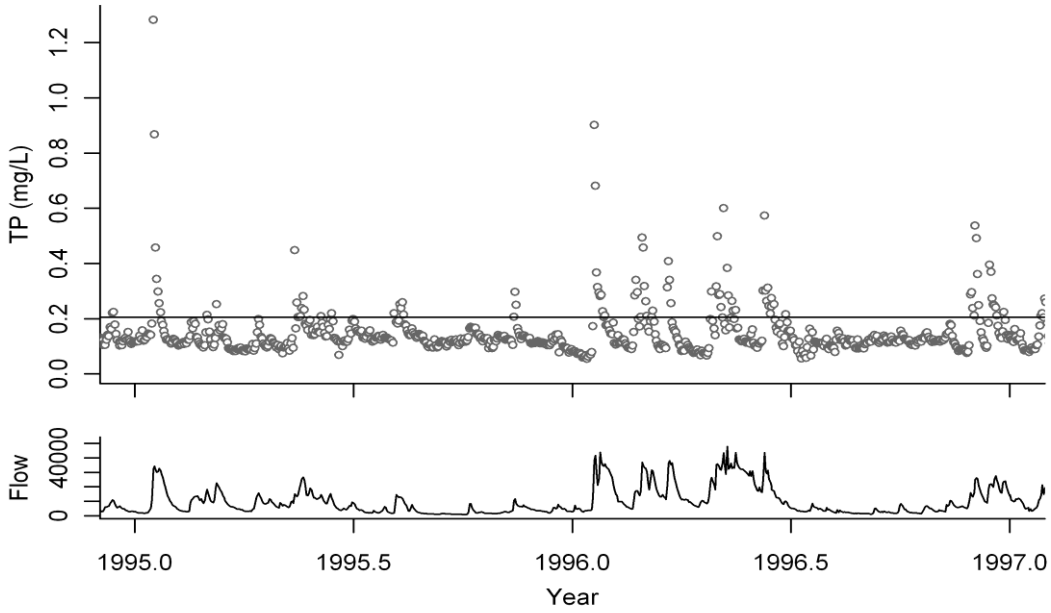
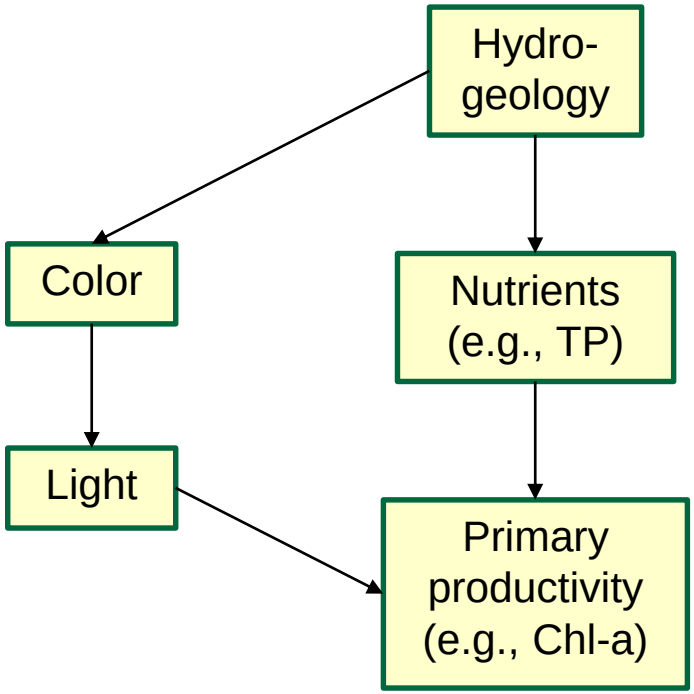
Unexplained Variability in Stressor-Response Relationships

- Measurement error:
  - Nutrient measurements are highly variable, even during baseflow.
- What summary statistic of nutrients should we be calculating?
  - Annual average baseflow concentration?
  - Flow-weighted concentration?



Unexplained Variability in Stressor-Response Relationships

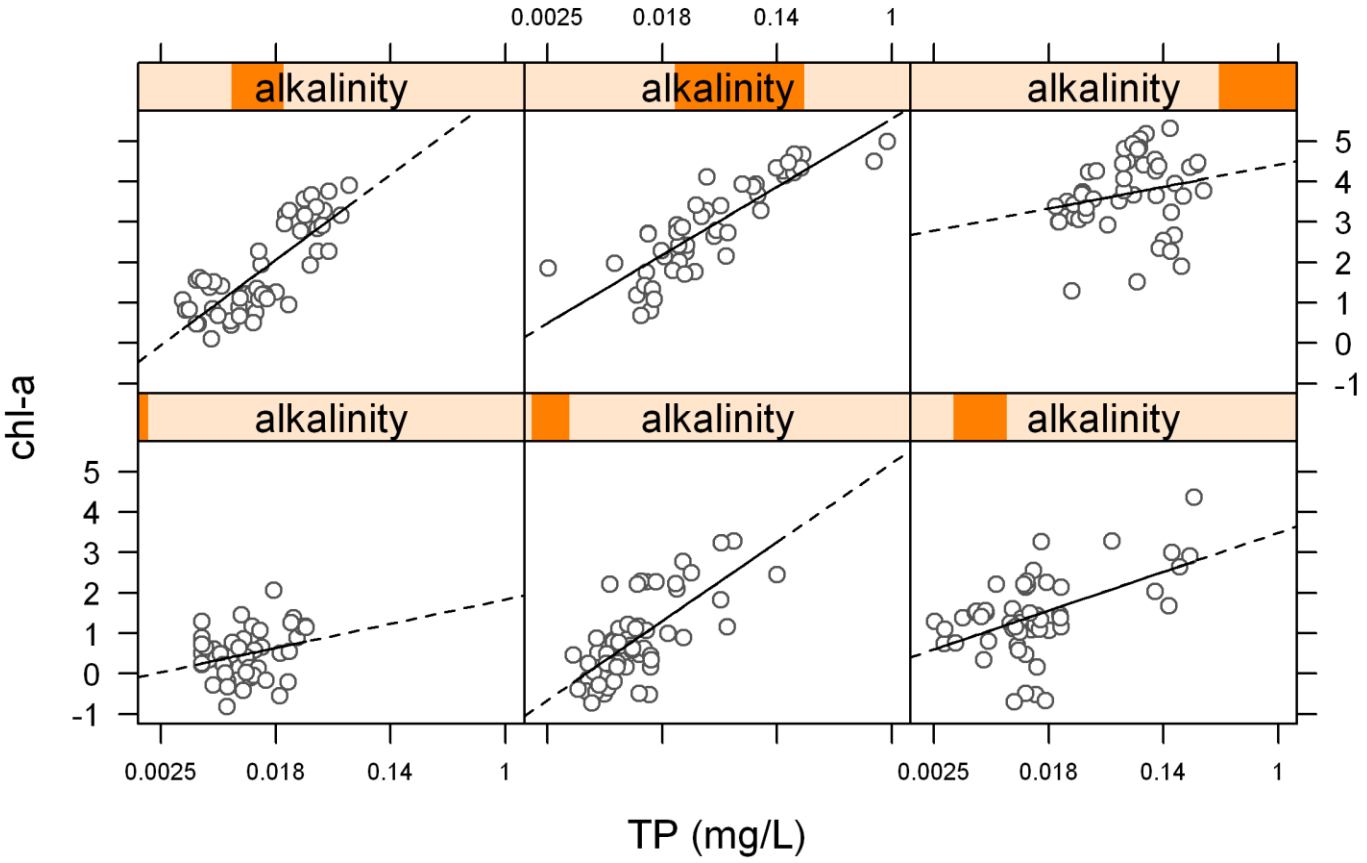
Other unmodeled factors:



Approaches for Addressing Variability in Relationships

- Classification
  - TREED models
- Hierarchical models

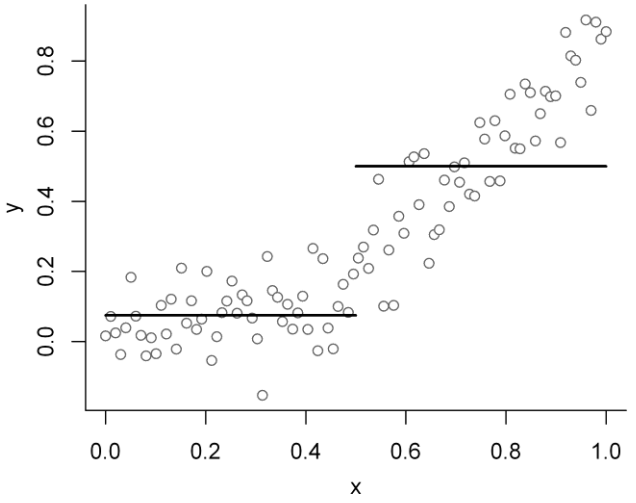
Classification Example: Lakes



TREED Models

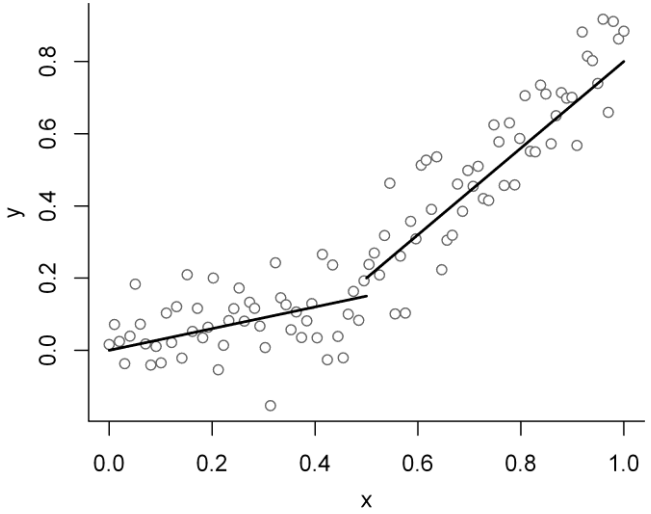
CART regression:

- Split data into groups with similar values of the response variable.



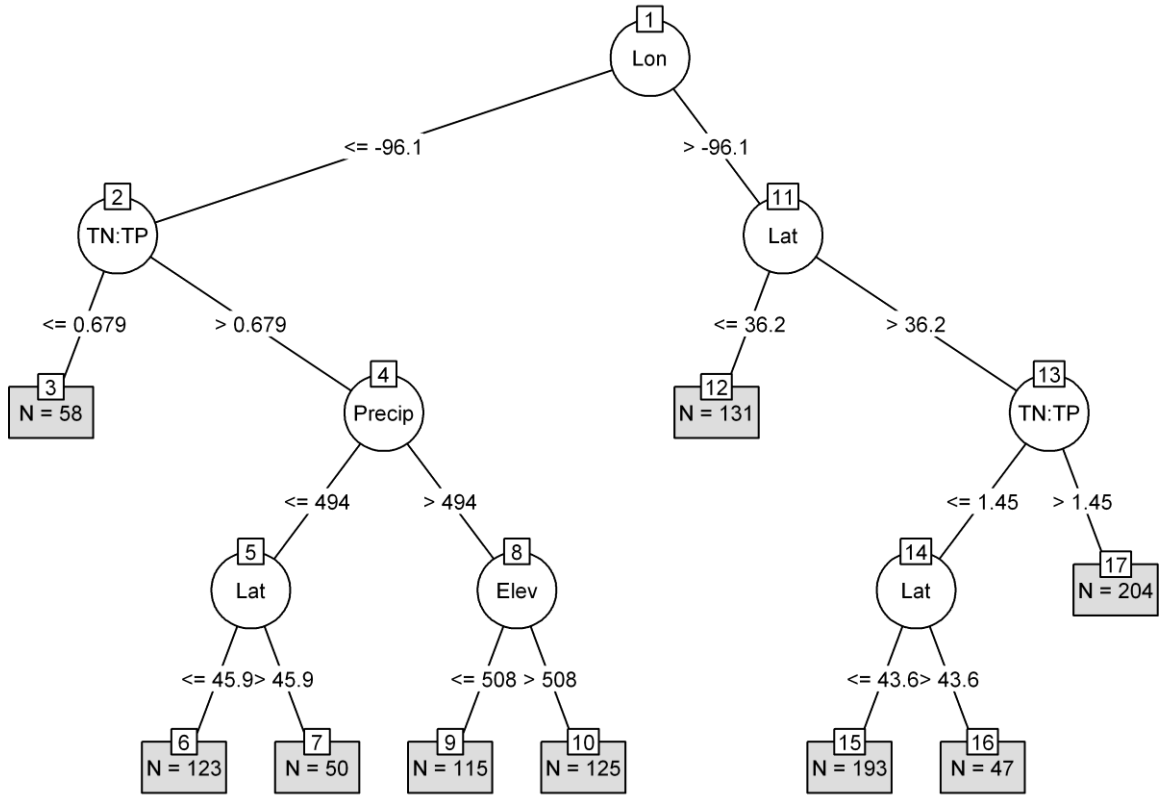
TREED regression:

- Split data into groups with similar relationships between specified variables (e.g., chl *a*, TN, and TP)

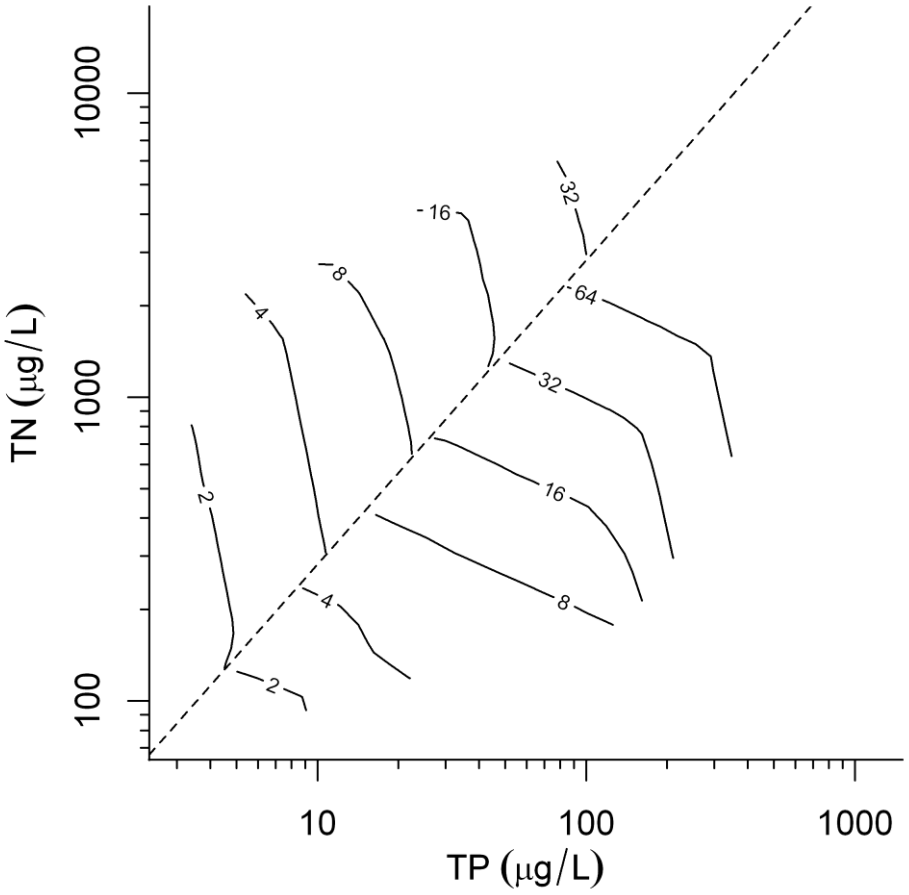


TREED Models

Preliminary classifications can be identified from the data that maximize the predictive accuracy of the stressor-response model.



TREED Models: Preliminary Results

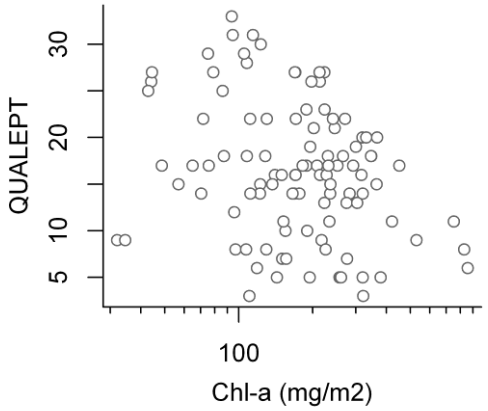


Filled circles N:P > 28

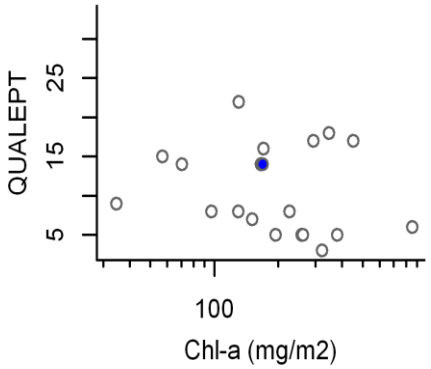
Open circles N:P < 28

Contour lines = Chlorophyll *a* in µg/L

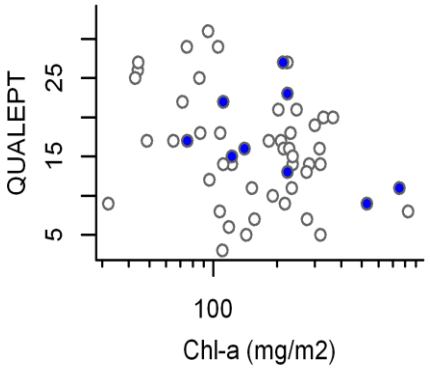
Classification Example: Streams



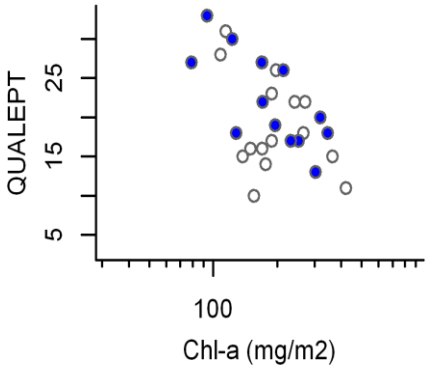
Habitat poor



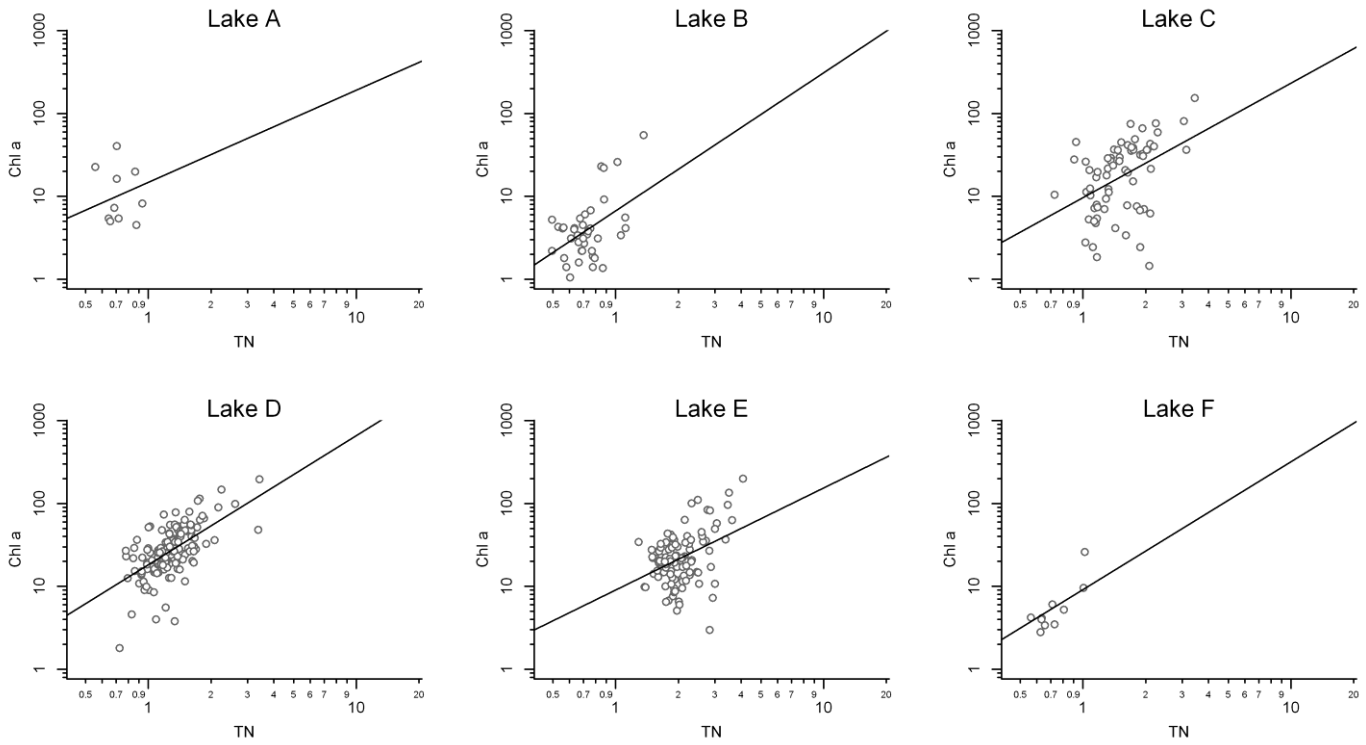
Habitat fair



Habitat good



Hierarchical Models



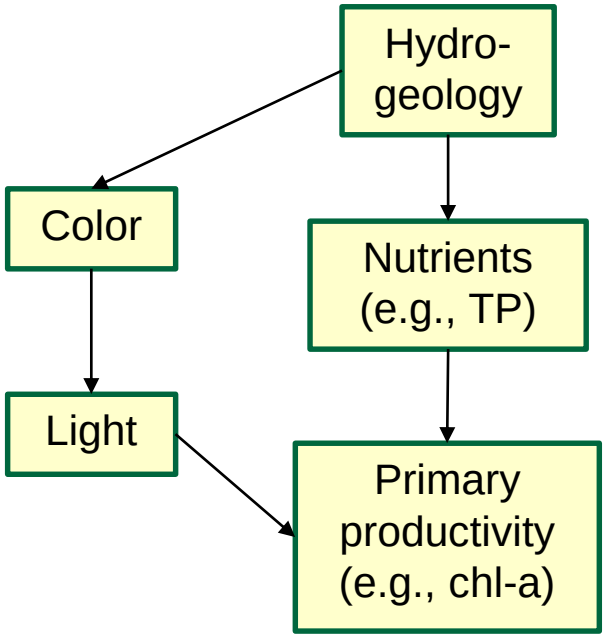
- Instead of classifying, model relationships in each waterbody separately.
  - Fewer variables can confound relationships when models are fit within a single waterbody.
- Hierarchical models allow us to relate each waterbody-specific model to an overall trend.

When is a Stressor-Response Relationship "Good" Enough?

- Does the estimated relationship accurately represent the relationships shown in the conceptual model?
- Is the estimated relationship precise enough to usefully inform criteria derivation?

Accuracy: Are All Relevant Covariates Considered?

- To identify potential confounding variables, select variables along each "backdoor" path linking the stressor with the response variable.
- Color can directly influence light availability and primary productivity, and is influenced by the hydrogeology of the lake watershed.



Accuracy: Are All Relevant Covariates Considered?

How strongly are covariates correlated with the stressor variable?

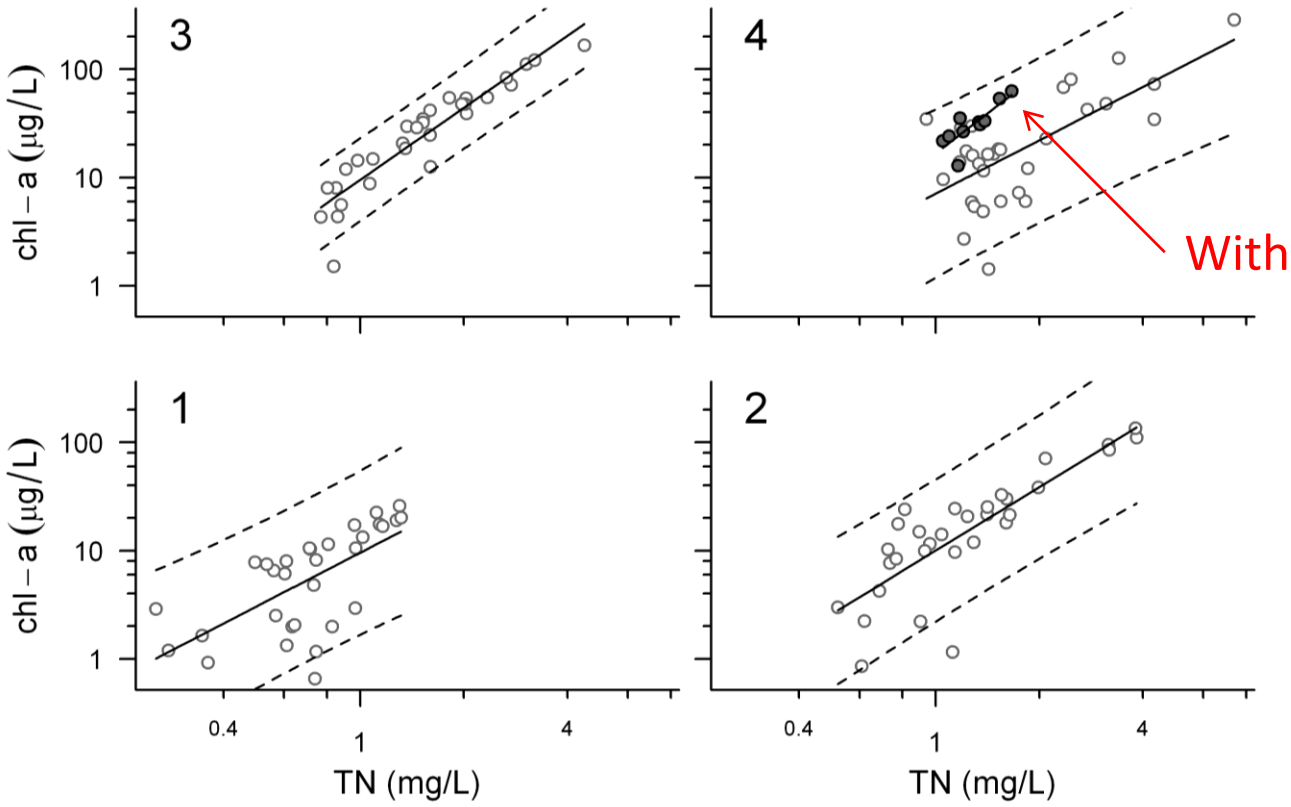
	All data	Within classes	
		Average	Range
log (conductivity)	0.36	0.14	0.06 – 0.23
log (color)	0.26	0.15	0.01 – 0.35

Correlation coefficients between TN and different covariates

Accuracy: Is the Estimated Relationship Consistent With Other Estimates?

- How similar are models computed within a waterbody and models computed across different waterbodies?
- How similar is the estimated model to other models documented in the literature?
- Does the inclusion of covariates in the model substantially alter the estimated stressor-response relationship?

Example: Comparing Within-Lake and Across-Lake Models

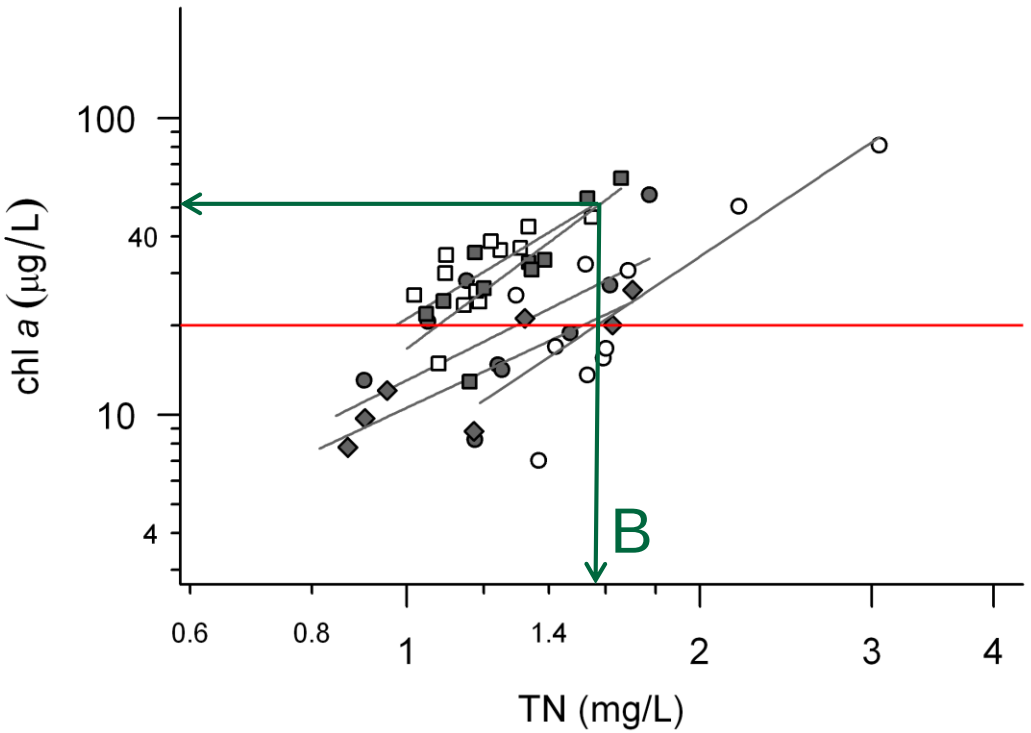


Precision: Is a Stressor-Response Model Precise Enough?

- Commonly reported regression statistics include:
  - R^2 : The proportion of variability explained by the model relative to a horizontal line.
  - *p-value* : The probability that observed data would occur if the slope were 0 (i.e., a horizontal line).

✓ **Neither of these statistics directly answer our question.**

Is the Model Precise Enough to Usefully Inform Decisions?



The criterion that protects the least sensitive lake (B) allows chl *a*= 50 µg/L in the most sensitive lake.

Presenting model precision in terms of the effects of a criterion on different classes of waterbodies can be most informative.

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Lessons Learned

- Simple linear regression, combined with classification, provides a model that is easily interpreted and communicated.
- Classification is critical for maximizing precision and accuracy of estimated relationships.
- Further research will improve the accuracy and precision of estimated relationships. Some example questions:
  - How can we best quantify nutrient concentrations in streams?
  - How can we best measure primary productivity in streams?